GEOTHERMAL WELL COMPLETIONS IN CERRO PRIETO

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ABSTRACT

Geothermal well completion criteria have evolved from 1964 to this date. The evolution started with the common techniques used in oil-well completion and gradually changed to accommodate the parameters directly related to the mineralogic characteristics of the geothermal fluids. While acceptable completions can now be achieved, research techniques and data collection should be improved to optimize the procedures.

DISCLAIMER

Considering that the main objective in drilling a geothermal well is that of obtaining the best energetic results possible and under the circumstances that prevail in the reservoir in which it is located we think that well completion should be immediate in order to reach these objectives, considering that some aspects, different to those common to oil wells, do exist.

This work presents some experiences aimed at adequately defining which zone or zones should be subject to exploitation, given the case. The result has been the acquired and observed experiences in this field. Some of the aspects or parameters that were used are common to oil wells, however some, maybe the most significant and trascendental, are geothermal well problems.

In this paper we will refer to well completion with regard to the operations, data recollection and analysis, and mechanical performances necessary to exploit the most favorable stratum, and under this same criteria we will present this work; because deciding when the drilling of a well stops is part of its completion.

During 1964, when drillings began, the criterion was extremely poor, the essence on this lies really in finding the reservoir with the most geothermal energy and the most favorable permeability conditions, without forgetting possible contamination of upper or lower layers containing lower temperature water with scaling materials, to this date this has been possible by analyzing the parameters which we point below and that were totally unknown when drilling started.

PARAMETERS USED DURING DRILLING AND WELL COMPLETION

The group of parameters used in this field to determine the most favorable zone or zones and design a completion may be grouped into; Lithological aspects, cement types, mineral content of the reservoir being drilled, temperature logs and the temperature of the circulating mud, which has been used for drilling. These data are summarized in Table 1.

The lutite coloring which may be either light or dark gray, has a minor significance on greater temperatures which cause metamorphism associated with this coloring. The percentage of sandstone found in the lutites, may mean a larger or smaller stratum permeability and a larger or smaller production directly related to the larger or smaller sandstone percentage. When there is evidence of crushing due to tectonism or the presence of faults or fractures, permeability is logically found and results may be more satisfying. The original temperature of cements and minerals also indicates more or less thermal content which in each case should agree with the temperature logs and with the quality aspects of circulating muds. Electric logs whose design is not specifically related to temperature, but that mark out with great precision the different formations that have been penetrated is an information more closely associated with the above.

LOCATION OF STUDIED WELLS

The Cerro Prieto field has been divided into three main areas, Cerro Prieto I, II and III which are related in a certain way by the depth, pressure and temperature of the reservoir. In Figure 1 we indicate the pressure of the wells that are analized here, and that as a matter of fact, are located in the areas mentioned above.

In order to give you an idea of the lithological column which can be generalized in all the field and that only varies in thickness, in Table 2 we emphasize certain kinds of coloring with lutitic material and with some sandstone content, mainly in the zone related to the reservoir, in this work we will only note this part of the lithological column, being the rest only to explain which are the general lithological conditions that should be penetrated during drilling.

It has been possible to find in the reservoir certain kinds of cements and minerals that, according to evaluations and studies, have formed and deposited on a certain environment and mostly on certain temperature levels. This is illustrated in Figure 2, and this way we can clearly appreciate that they part from the calcite up to the epidote. The origin of those minerals is associated to a higher temperature level.

This precise aspect is the most interesting for with the proper use of this information it is relatively easy to define the layers or zones that have a mineral content, as those pointed out previously where there is a higher permeability that has permitted hot water flow to take, in a suspension form, those minerals which have deposited in the formation. In Table 3 we point out the mineral and temperature relation detected during drilling in the Cerro Prieto Field, depending on the analysis on this information, the final results while exploiting completed wells with this criteria, have been very satisfactory.

It is necessary to explain that deposits which have developed on a past period of time and in a high temperature environment, may have to date suffered contamination of salts whose temperature is lower and this has caused phenomena that have favored water infiltrations which deposit salts related to lower temperatures together with salts formed in higher temperatures. This has to be carefully analized and interpreted, in order to distinguish this situation, because completion may cause severe scaling problems if these formations are reached.

Besides the parameters mentioned above which are closely related to temperature, it is essential to define that stratum that offers greater porosity and above all permeability, and this is accomplished using the temperature logs and qualitative temperature of drilling muds. A series of two or three logs in a twenty four hour interval is the most convenient means of determining this situation, without leaving out their confrontation with the other parameters mentioned, in order to confirm that the conclusions among cements, minerals and temperature logs are valid. This information will permit us to decide first, if a reservoir with adequate energetic content as to complete the well has been penetrated or on the contrary continue drilling until bedrock and other more convenient strata are reached. This is the first conclusion that should prevail in a drilling routine; when thermal logs show a favorable condition, an analysis should be done of all former parameters to conclude with certainty a hot reservoir has been penetrated in adequate length and above all, with the desired energetic content.

Sometimes, partial penetration in the reservoir is enough, other times it must be totally penetrated, under this last circumstance, temperature logs will show drastic increases or decreases in temperature, clearly defining the possibly exploited reservoir and its anormality, in some cases there may be excessive decreases in temperature and in larger depths this favors a temperature increase which may indicate another hot stratum, however, as we cross completely hot and permeable porous zones, drilling is excessively complicated and this increases drilling time and costs.

WELL COMPLETION ANALYSIS

Considering the parameters which we have mentioned, we will make a brief analysis of other well completions trying to emphasize the most significant aspects in regard to completion criteria. Of these wells, M-3 and M-45 were completed during a time before cements and hydrothermal minerals were applied, nevertheless, by comparing the respective figures of methods used in that period of time, one may appreciate the difference in one aspect or another.

WELL M-3 -- This well was built in 1964. The sandstone percentage and the mineralogic content corresponding to the producing zone are indicated in Figure 3. In this case, drilling fluid temperature, two temperature logs obtained with Kuster equipment and electrical logs, were used.

Drilling temperatures higher than 70°C. coinciding with formations of silica cement predominating from 773 to 932 m., and mud temperatures of 63°to 71°C. decreased as calcareous cements appeared. Correlated temperature logs reported an increase in temperature as the zone mentioned above was approached, and decreased in front of lutitic bodies, as indicated at a depth of 900 m. approximately.

WELL M-45 -- This well is located in the Southern part of the field and its physical completion parameters are shown in Figure 4. Its lithological column is made up of sandstone and shale intercalations, the latter predominating, 80% was the maximum percentage - reported in some cases, but the greater part is close to 20%, we clearly appreciate at least three lutitic bodies marked out by the samples collected from the flow line and by electrical logs, coinciding with temperature decrease of drilling mud.

Silica cements with minimum carbonate amounts predominate in this well above 1500 m., likewise, the mineral dominating in this case is epidote, in spite of the fact that chlorite and some pyrite are reported. Completion coincided with higher differential temperature bodies, that in some cases exceeded 10°C., sandstone layers, but above all the epidote zone, are reached. This well has given very good results, in spite of mechanical problems that have appeared after its completion.

WELL M-51 -- Physical parameters used for the completion of this well are shown in Figure 5. Well M-51 located in Block II was a semi-exploratory type well, with a depth of 1600 m., we found intercalations of sandstone and shales that latter of medium to dark gray in color, the sandstone bodies have a regular development and sometimes reach 80% but shales are definitely predominating, specially in the producing zone, this is definitely comfirmed by electric logs.

Drilling fluid temperatures were significant mainly below 1500 m. and general differentials that nearly reached 10°C. in temperature logs were moderate except T-2, that showed an energetic increase reaching 180° C. at the bottom of the well.

Sandstone calcareous cements with silica acquires more preponderance below 1530 m. the latter corresponding with epidote presence, while above this depth, we find pyrite, chlorite and biotite; the lack of mineralogic analysis during the time this well was completed and only with temperature, electric and lithological logs, probable greater thermal potential found below 1550 m. was unnoticed, making us think this well should have been deepened.

WELL M-110 -- This well is located to the East of Well M-130 and in the area of Block III. The physical parameters used in the completion of this well are illustrated in Figure 6.

Here we find the lithological column made up of light, medium and dark shale and sandstone intercalations, below 1850 we find powerful black color shales. The electric logs clearly agree with lithological conditions and sandstone content whose average is barely 40%, then again they report a great amount of lutitic bodies that separate sandstone layers.

The cements in the sandstones in this case, are predominantly silica and scarcely any carbonate is found, that precisely correlates with black lutite below 1850 m., above this depth it appears less frequently and we find as predominant minerals between 1680 m., towards 1850 m., epidote and pyrite from 1850 m., we find milky quartz, chlorite and pyrite and the same amount of epidote.

Differences between temperature logs and mud circulation exceed 10°C. in several sections and these correspond precisely with groups of sandstone which have marked decreases in lutitic layers.

WELL T-366 -- This is a very interesting well located in Block III, the deepest of the group that has been mentioned previously, physical parameters used for its completion are shown in Figure 7. Here the lithological column was made up of alternated shales and sandstones with shales predominating, the average sandstone content is 40% and in some cases lutitic bodies were reported, as the one located around 2830 m., borehole cuttings showed shale fracture, being this in a block form and of different sizes than those regularly cut by the bit used, the differential temperatures in the drilling mud nearly reached 10°C. and temperature logs obtained with Kuster equipment reported maximum temperatures of 240°C.

Correlating the lithological column and sandstone content with electric logs, we see the relatively low permeability that in this case was found, the cements predominating were silica and in some intervals calcium carbonate, epidote content with some pyrite and milky quartz was definitely dominant within minerals.

The completion of this well, covering from 2400 m. to the bottom, alternating "blind" and slotted casings, was decided, considering the uncertainty of the relative low permeability.

To give you an idea of the results accomplished on cemented wells, this is summarized in Table 4, pointing out initial productions of water and steam, undoubtedly influenced by the larger or smaller energetic quality of the reservoir and of course, the greater or smaller quality of the completion. In this same table we present actual data showing certain decline in the wells evaluated and also shows the maximum established temperatures of the reservoir obtained in each case.

CONCLUSIONS AND RECOMMENDATIONS

With the application of cements and hydrothermal minerals, the reliable selection of producing zones that may be subject to exploitation, has been clearly defined. See Table 5. However, these parameters necessarily should be carefully used, relating them to the others that were used since the beginning, and this way attain a more adequate conclusion. In each case, it is possible that we find concentrations with lower temperature minerals in zones with cements or minerals whose origin was a high temperature, but actual conditions have permitted this concentration, possibly with a thermal decrease. The rational analysis to this respect, will give a desirable result.

We must consider that the lithological, mineralogical and petrographic analysis of hydrothermal minerals and metamorphic effects, through rock chemistry, and with the use of X rays, is more sophisticated with a tendency to detect firmly the thermal limits in each mineral series, and this way defining with detail the zones to be exploited.

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PARAMETERS USED DURING DRILLING & WELL COMPLETION

LITHOLOGIC COLUMN

COLOR OF SHALE ROCKS

SANDSTONE PERCENTAGE FOUND IN FLOW LINE SAMPLES

BLOCK CUTTINGS

FAULT VEIN

* CEMENT IN SANDSTONES

CALCIUM CARBONATE

SILICA

* HYDROTHERMAL MINERALS

DRILLING MUD IN AND OUT TEMPERATURE

TEMPERATURE LOGS

ELECTRIC LOGS

* APPLIED FROM 1978
UP TO DATE

TABLE N° 1

STRATIGRAPHIC SECTION OF THE CERRO PRIETO GEOTHERMAL FIELD

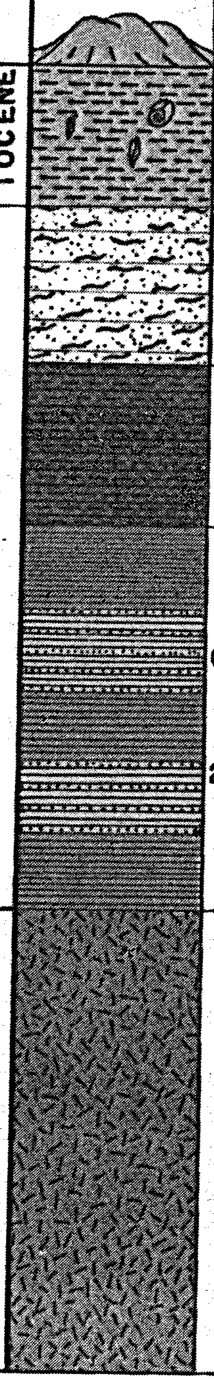
ERA	PERIOD	EPOCH	PETROLOGY	THICKNESS	LITHOLOGICAL DESCRIPTION
CENOZOIC	QUATERNARY	PLEISTOCENE		500 TO 2 300 m.	ANDESITE, CLAYS, FINE TO COARSE SAND QUARTZ, SILICA, FELDESPAR AND SCARCE GRAVEL DIABASE
CENOZOIC	TERTIARY			1 TO 100 m.	CLAYSTONE SAND, SANDSTONE.
CENOZOIC	TERTIARY			100 m.	BROWN COLORED SHALE, INTERCALATED WITH SANDSTONE.
CENOZOIC	TERTIARY			GREATER THAN 2 200 m.	GRAY TO BLACK SHALE, ALTERNATIVE WITH SANDSTONES LIGHT GREYISH.
MESOZOIC	CRETACEOUS	SUPERIOR		?	GRANITE BIOTITE.

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TABLE 2

ACTUAL TEMPERATURES CORRESPONDING TO CEMENTS AND MINERALS AT CERRO PRIETO

MINERALS AND CEMENTS ZONE	TEMPERATURE °C
CALCIUM CARBONATE ZONE	60° - 200°
CALCIUM CARBONATE AND SILICA ZONE	150° - 250°
TRANSITION ZONE	150° - 250°
EPIDOTE AND SILICA ZONE	200° up to over 300°

TABLE N° 3

PRODUCTION AND MAXIMUM TEMPERATURE OF ANALIZED WELLS

WELL	INITIAL PRODUCTION TON./HR.			ACTUAL PRODUCTION			TEMP.
	DATE	STEAM	WATER	DATE	STEAM	WATER	MAX. °C
M - 3	(I/65)	46.8	332.3				269.0
M - 45	(VIII/77)	32.1	28.1	(I/80)	23.8	9.0	315.0
M - 51	(II/79)	117.7	170.3	(I/80)	88.2	146.3	331.0
M - 110	(XI/79)	185.3	335.7				320.0
T - 366	(VII/79)	212.3	308.5				328.5 *

* ESTIMATED TEMPERATURE

TABLE N° 4

CONCLUSIONS AND RECOMMENDATIONS

WITH THE CRITERIA ABOVE INDICATED, THE RESULTS HAVE BEEN PROMISING THAT ALL ASPECTS SHOULD BE IMPROVED TO SUPPORT COMPLETIONS FUNDAMENTALLY ON LITHOLOGIC AND MINERALOGIC ANALYSIS, AS WELL AS PETROGRAPHY OF HYDROTHERMAL MINERALS AND METAMORFHISM, GEOCHEMISTRY OF ROCKS, AND X RAY ANALYSIS, TO DETERMINE CAREFULLY THE MINERALS WHOSE GENESIS IS CLOSELY RELATED TO DIFFERENT THERMAL LEVELS, AND THUS EXPLOIT IN A SELECTIVE FORM THE SIMILAR LITHOLOGIC AND MINERALOGIC ZONES THAT WOULD GUARANTEE THE BEST PRODUCTION.

TABLE 5

LOCATION OF STUDIED WELLS

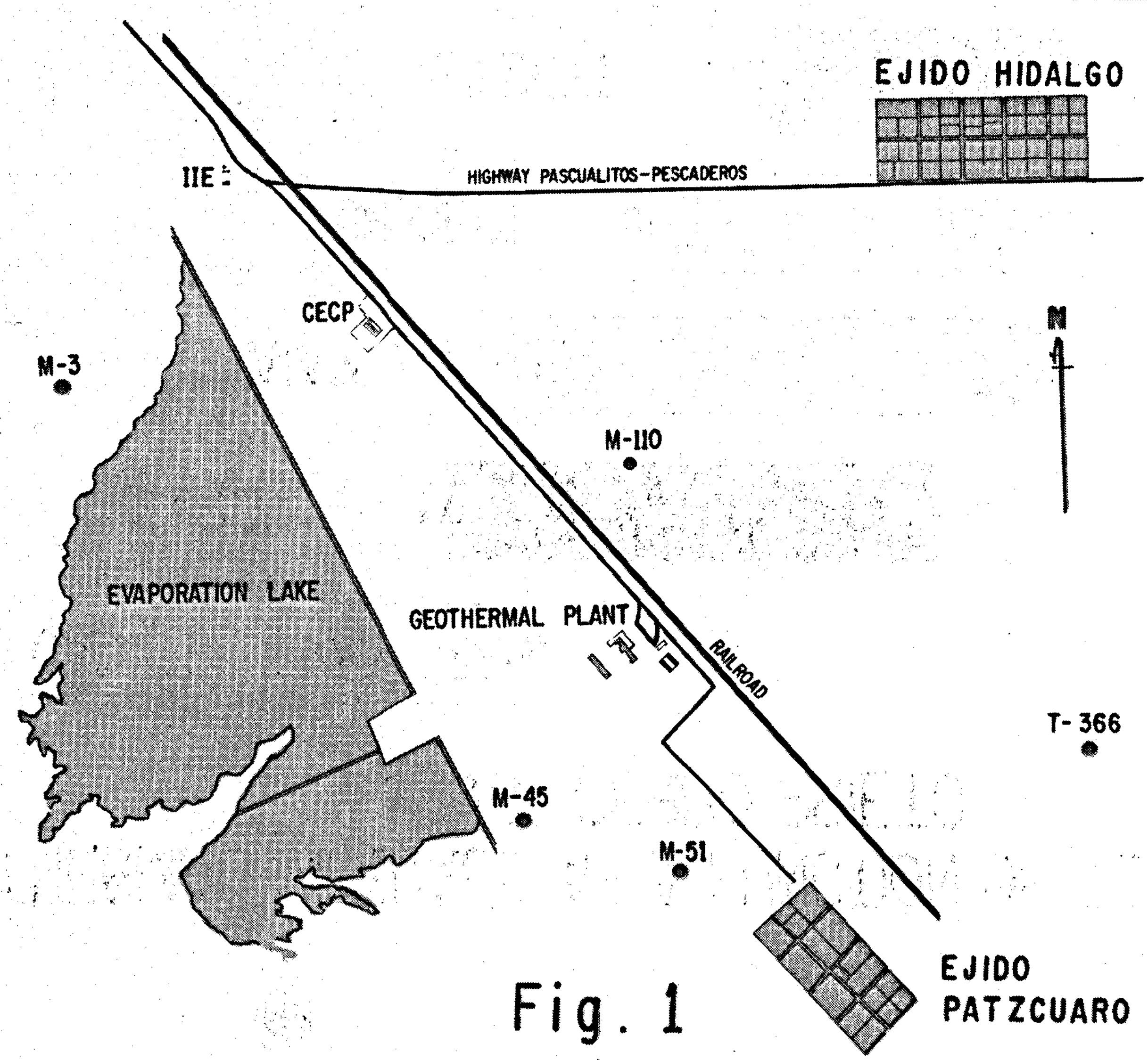


Fig. 1

HIDROTHERMAL MINERALS AS A FUNCTION OF TEMPERATURE AT CERRO PRIETO

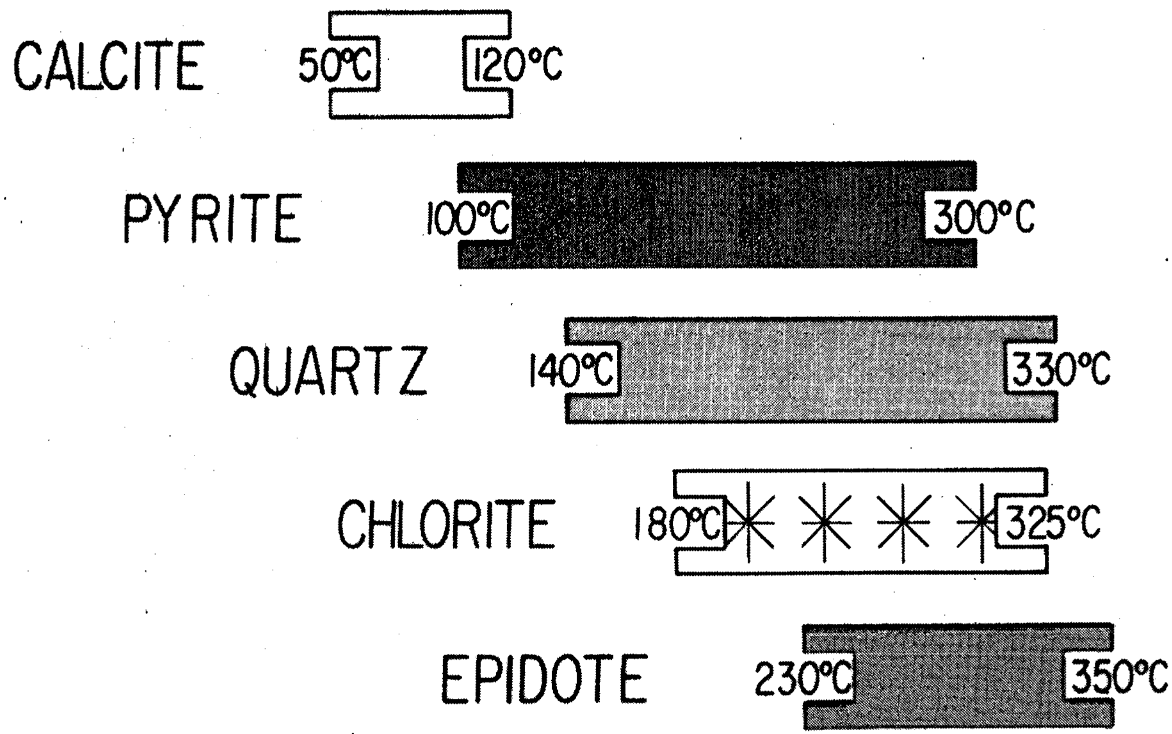


Fig. 2

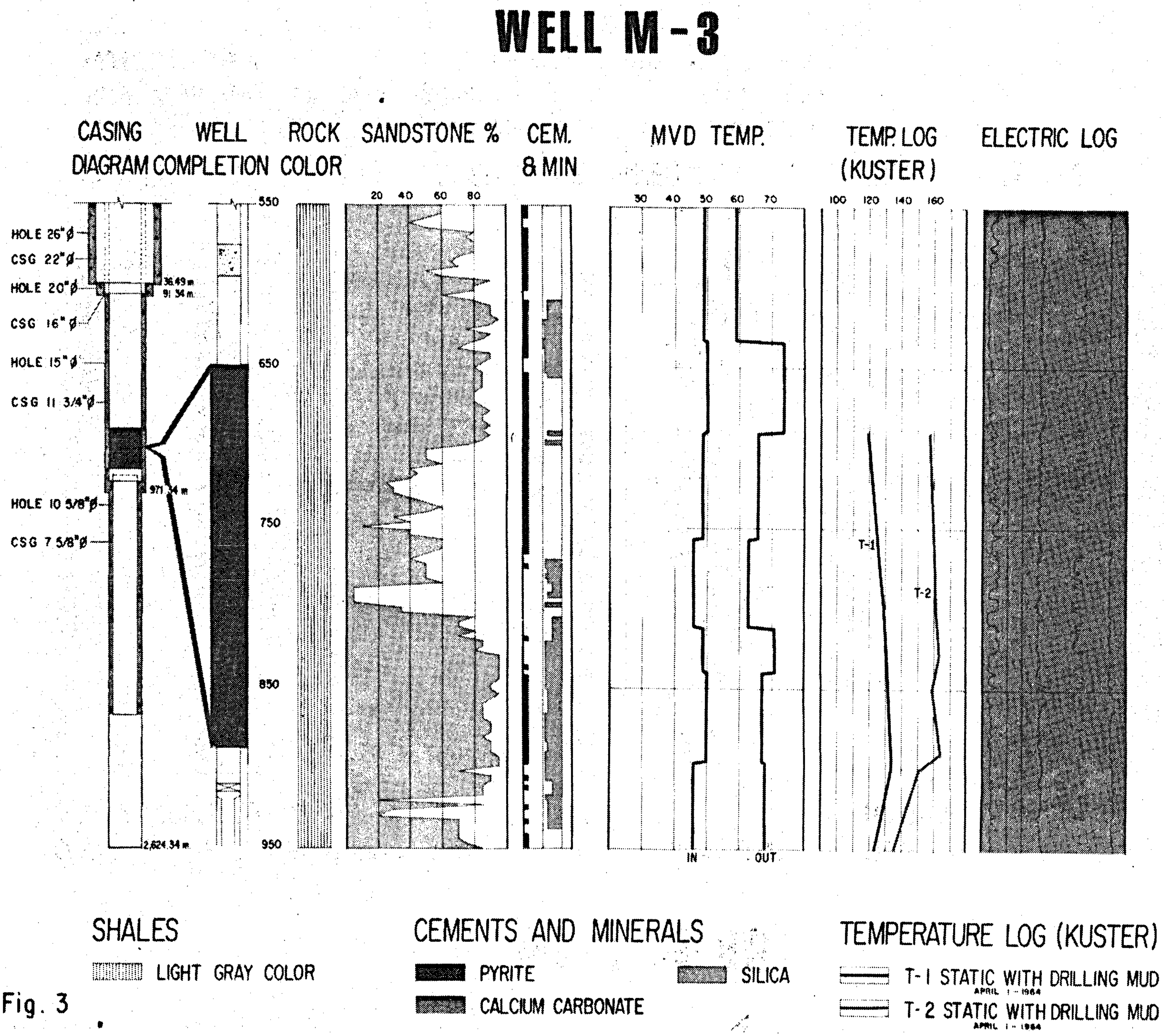
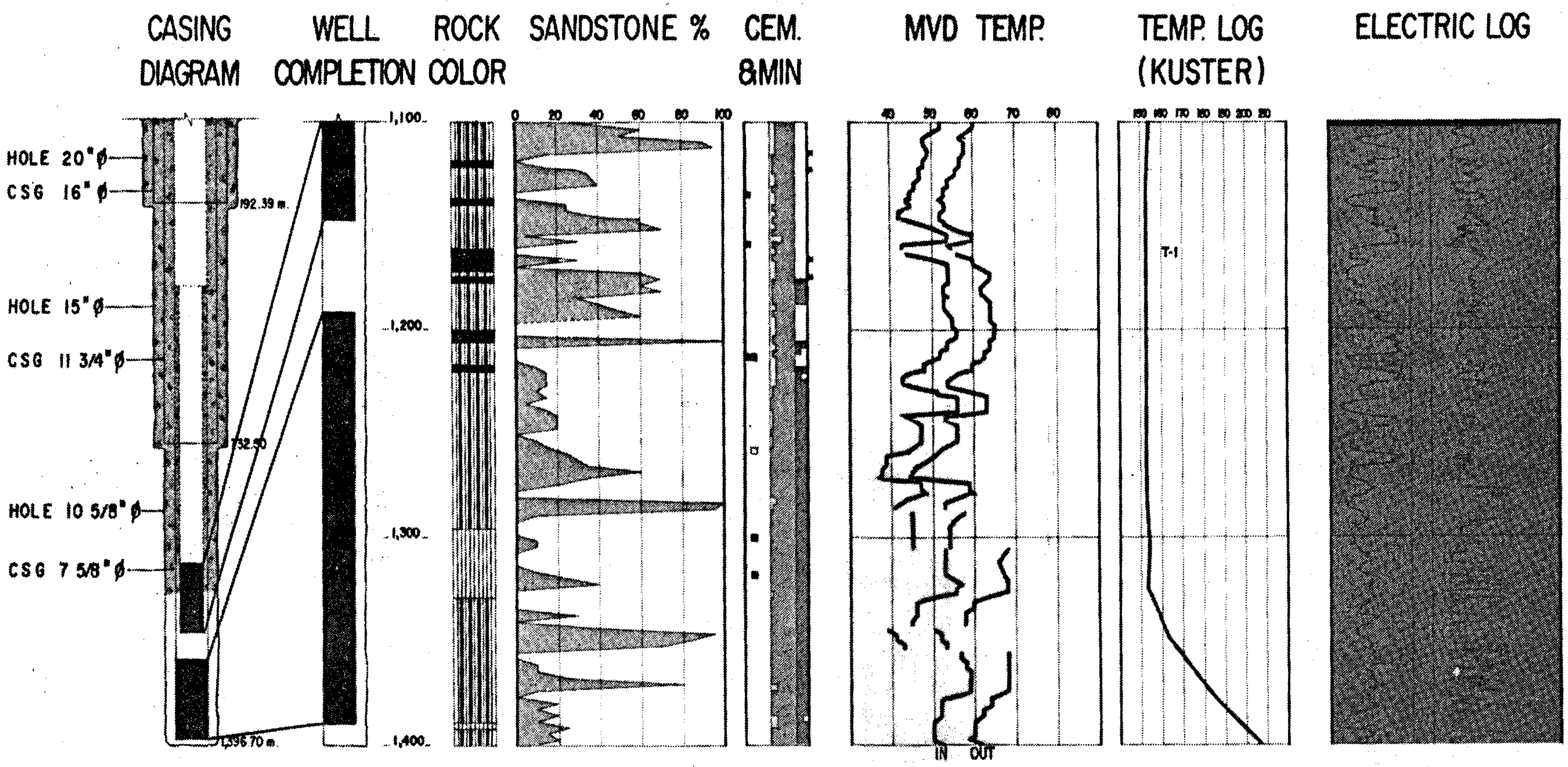

WELL M-3
CASING DIAGRAM
WELL COMPLETION
ROCK COLOR
SANDSTONE %
CEM. & MIN
MVD TEMP.
TEMP. LOG (KUSTER)
ELECTRIC LOG
HOLE 26"Ø
CSG 22"Ø
HOLE 20"Ø
CSG 16"Ø
HOLE 15"Ø
CSG 11 3/4"Ø
HOLE 10 5/8"Ø
CSG 7 5/8"Ø
36.49 m
91.34 m
971.34 m
2,624.34 m
550
650
750
850
950
20 40 60 80
30 40 50 60 70
100 120 140 160
T-1
T-2
IN
OUT
SHALES
LIGHT GRAY COLOR
CEMENTS AND MINERALS
PYRITE
CALCIUM CARBONATE
SILICA
TEMPERATURE LOG (KUSTER)
T-1 STATIC WITH DRILLING MUD
T-2 STATIC WITH DRILLING MUD

Fig. 3

WELL M-45



SHALES

- LIGHT GRAY COLOR
- MEDIUM GRAY AND DARK COLOR
- BLACK COLOR

CEMENTS AND MINERALS

- PYRITE
- WHITE QUARTZ
- CALCIUM CARBONATE
- SILICA
- EPIDOTE
- CHLORITE

TEMPERATURE LOG (KUSTER)

- T-1 11 HRS WITHOUT CIRCULATION

Fig. 4

WELL M-51

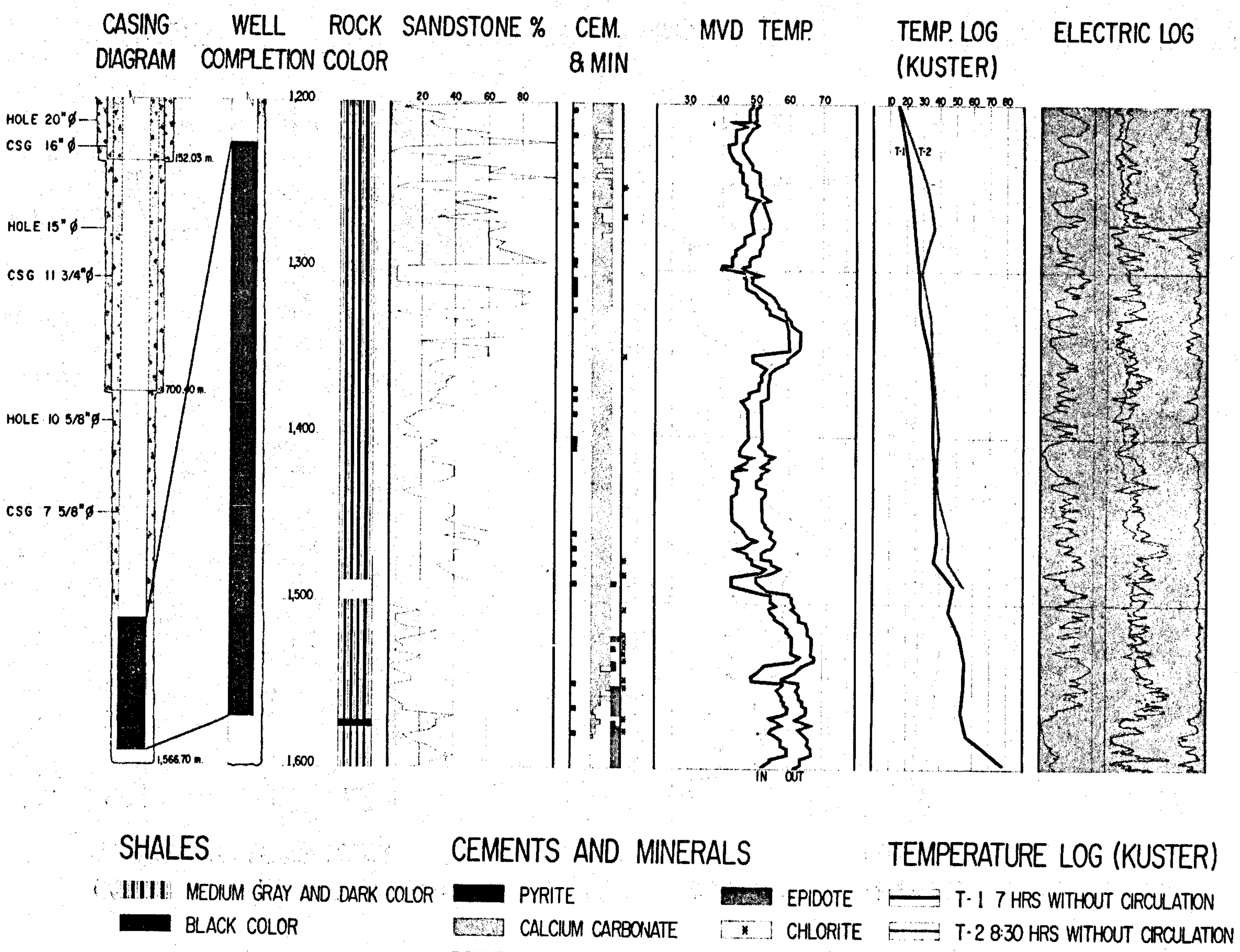


Fig. 5

WELL M-110

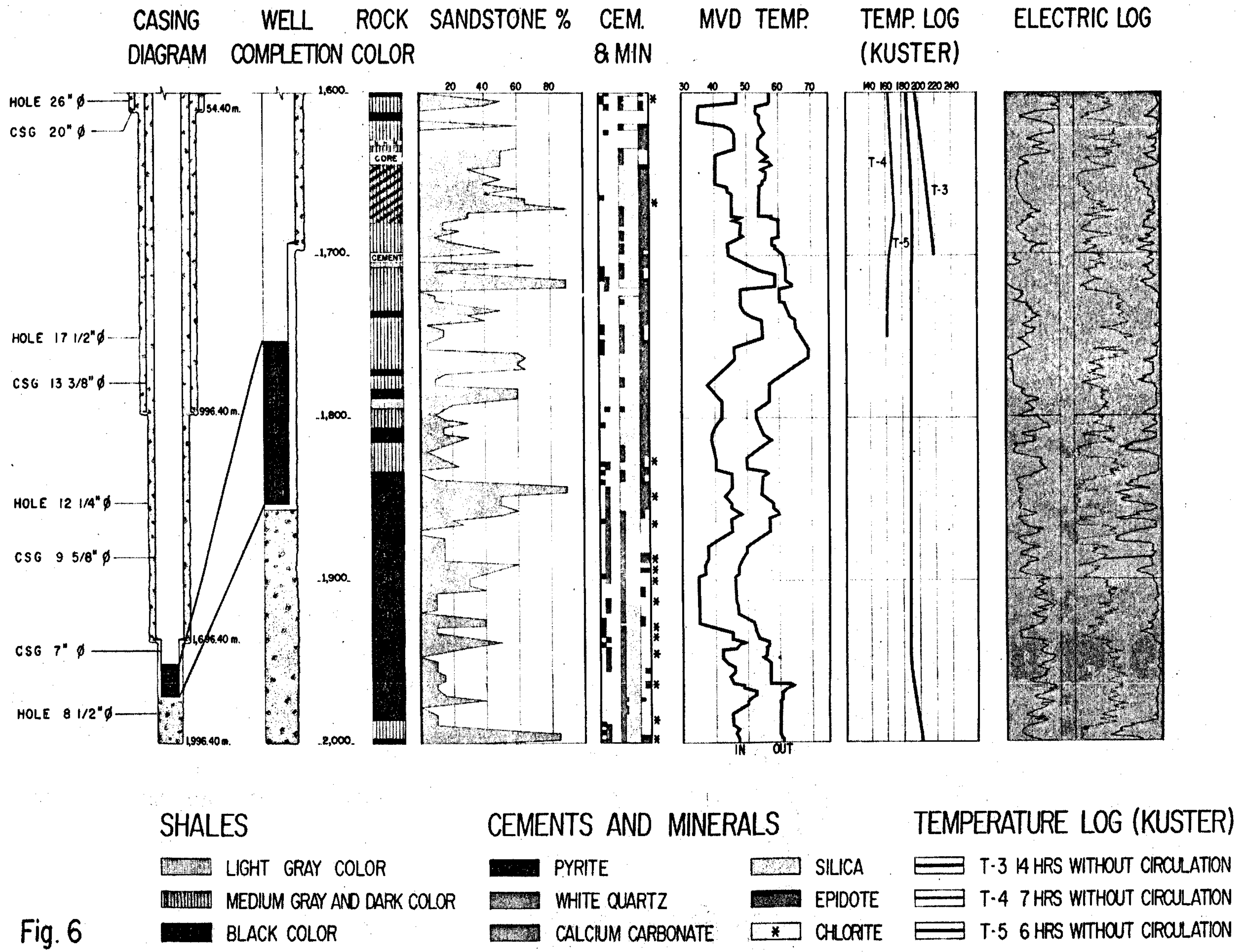
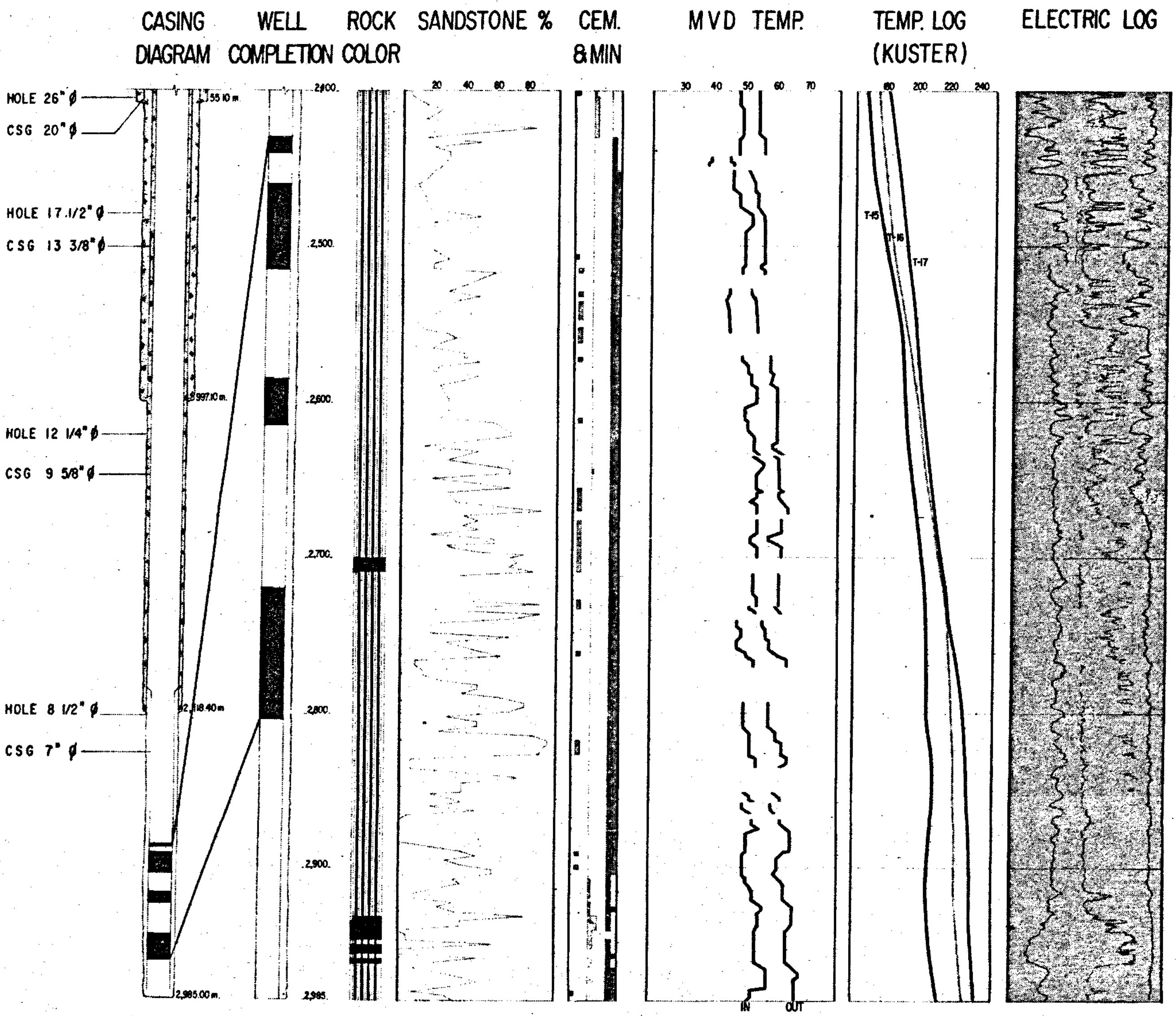


Fig. 6

WELL T-366



SHALES

- MEDIUM GRAY AND DARK COLOR
- BLACK COLOR

CEMENTS AND MINERALS

- PYRITE
- WHITE QUARTZ
- CALCIUM CARBONATE
- SILICA
- EPIDOTE

TEMPERATURE LOG (KUSTER)

- T-15 7 HRS WITHOUT CIRCULATION
- T-16 10:30 HRS WITHOUT CIRCULATION
- T-17 13:30 HRS WITHOUT CIRCULATION

Fig. 7